Doctor of Philosophy Program in Mathematics
(International Program/ revised 2012)

Department of Mathematics

Program Title Doctor of Philosophy Program in Mathematics
(International Program)

Degree Title Doctor of Philosophy (Mathematics)
Ph.D. (Mathematics)

Place of Instruction

Faculty of Science, Silpakorn University, Sanamchandra Palace, Nakhon Pathom Province

Objectives

1. To produce mathematicians who are capable of conducting research of an international standard
2. To produce and improve the quality of mathematics instructors in college and higher levels, contributing to solve the problem of short supplies of mathematics instructors in colleges and universities
3. To serve universities' employees development plan

Student qualifications

1. Type 1 (Thesis)

Type 1.1 Thesis equivalent to 48 credits

Graduates of a master's degree or equivalent in mathematics or related fields, with a GPA of 3.25 or higher, or by department's approval

Type 1.2 Thesis equivalent to 72 credits

Graduates of a bachelor's degree with honors in science or equivalent in mathematics or related fields

2. Type 2 (Thesis and additional courses)

Type 2.1 Thesis equivalent to 36 credits and additional courses 15 credits

Graduates of a master's degree or equivalent in mathematics or related fields

Type 2.2 Thesis equivalent to 48 credits and additional courses 27 credits

Graduates of a bachelor's degree with honors or equivalent in mathematics or related fields

3. Candidates must pass an English test equivalent to a minimum TOEFL score of 500 (paper based) or 173 (computer based), or a minimum IELTS scores of 5.0, and the test must be taken no more than 2 years prior to the first date of program attendance. The eligible candidates may be allowed to use CU-TEP or TU-Get scores, at the minimum scores of 500 or 550 respectively, taken no more than 2 years prior to the first date of program attendance, for their proof of English proficiency. Eligible candidates who are unable to provide results of the specified English test may be accepted to the program with the approval of the department.
4. English candidates under Clause 1 and 2 Candidates must have all the qualifications specified in Clause 7 of Silpakorn University's Regulations on Graduate Study B.E. 2550 (2007) (and/or its revised version).

5. Candidates who do not have all the qualifications in 1-3 must have their cases considered by the department and the graduate school.

Structure of the Curriculum

Doctor of Philosophy Program in Mathematics offers 2 categories of curriculum.

Type 1 (Thesis)

Type 1.1 Students with a master's degree

Seminar (non-credit)	6	credits
Research study in mathematics (non-credit)	2	credits
Thesis (equivalent to)	48	credits
Total	**48**	**credits**

Type 1.2 Students with a bachelor's degree

Seminar (non-credit)	10	credits
Research study in mathematics (non-credit)	2	credits
Thesis (equivalent to)	72	credits
Total	**72**	**credits**

Type 2 (Thesis and additional courses)

Type 2.1 Students with a master's degree

Seminar (non-credit)	4	credits
Research study in mathematics (non-credit)	1	credits
Core courses	9	credits
Elective courses	6	credits
Thesis (equivalent to)	36	credits
Total	**51**	**credits**

Type 2.2 Students with a bachelor's degree

Required courses	9	credits
Seminar (non-credit)	6	credits
Research study in mathematics (non-credit)	1	credits
Core courses	12	credits
Elective courses	6	credits
Thesis (equivalent to)	48	credits
Total	**75**	**credits**

Course Requirements

Type 1

Type 1.1

511 791*	Seminar in Advanced Mathematic I	2(0-4-2)
511 792*	Seminar in Advanced Mathematics II	2(0-4-2)
511 793*	Seminar in Advanced Mathematics III	2(0-4-2)
511 794*	Research Study in Mathematics I	1(0-2-1)
511 795*	Research Study in Mathematics II	1(0-2-1)
511 891	Thesis (equivalent to)	48 credits

*Required courses whose credits are not counted toward graduation.

Type 1.2

511 594*	Seminar I	2(0-4-2)
511 595*	Seminar II	2(0-4-2)
511 791*	Seminar in Advanced Mathematic I	2(0-4-2)
511 792*	Seminar in Advanced Mathematics II	2(0-4-2)
511 793*	Seminar in Advanced Mathematics III	2(0-4-2)
511 794*	Research Study in Mathematics I	1(0-2-1)
511 795*	Research Study in Mathematics II	1(0-2-1)
511 892	Thesis (equivalent to)	72 credits

Type 2

Required courses

Type 2.1

511 791*	Seminar in Advanced Mathematic I	2(0-4-2)
511 792*	Seminar in Advanced Mathematics II	2(0-4-2)
511 794*	Research Study in Mathematics I	1(0-2-1)

Type 2.2

511 513	Abstract Algebra I	3(3-0-6)
511 515	Linear Algebra with Applications	3(3-0-6)
511 541	Mathematical Analysis	3(3-0-6)
511 594*	Seminar I	2(0-4-2)
511 791*	Seminar in Advanced Mathematic I	2(0-4-2)
511 792*	Seminar in Advanced Mathematics II	2(0-4-2)
511 794*	Research Study in Mathematics I	1(0-2-1)

Core courses

Type 2.1 Students with a master's degree are required to take 9 credits of core courses.

Type 2.2 Students with a bachelor's degree are required to take 12 credits of core courses. In addition, students must enroll in at least one course from each of the following two groups:

Mathematics Courses

511 514	Abstract Algebra II	3(3-0-6)
511 518	Universal Algebra	3(3-0-6)
511 532	Graph Theory	3(3-0-6)
511 544	Real Analysis	3(3-0-6)
511 546	Complex Analysis	3(3-0-6)
511 549	Functional Analysis	3(3-0-6)
511 642	Topology	3(3-0-6)
511 643	Differentiable Manifolds	3(3-0-6)

*Required courses whose credits are not counted toward graduation.

Applied Mathematics Courses

511 552	Theory of Ordinary Differential Equations	3(3-0-6)
511 558	Partial Differential Equations	3(3-0-6)
511 572	Probability Theory	3(3-0-6)
511 573	Stochastic Processes	3(3-0-6)
511 583	Numerical Analysis I	3(3-0-6)
511 681	Principles of Applied Analysis	3(3-0-6)
511 685	Advanced Numerical Methods	3(3-0-6)

Elective courses

Type 2.1 Students with a master's degree are required to take at least 3 credits of elective courses.

Type 2.2 Students with a bachelor's degree are required to take at least 6 credits of elective courses.

Students can select courses from either the following list or from core courses.

511 517	Lattice Theory	3(3-0-6)
511 519	Applicable Algebra	3(3-0-6)
511 521	Analytic Number Theory	3(3-0-6)
511 522	Algebraic Number Theory	3(3-0-6)
511 533	Combinatorics	3(3-0-6)
511 547	Advanced Complex Analysis	3(3-0-6)
511 548	Complex Dynamics	3(3-0-6)
511 555	Multigrid Techniques for Differential Equations	3(3-0-6)
511 556	Variational Techniques and Partial Differential Equations in Image Sciences	3(3-0-6)
511 557	Linear Differential Operators in Mathematical Physics	3(3-0-6)
511 559	Theory of Partial Differential Equations	3(3-0-6)
511 582	Mathematical Modeling	3(3-0-6)
511 584	Numerical Analysis II	3(3-0-6)
511 589	Information Theory	3(3-0-6)
511 601	Selected Topics in Mathematics I	3(3-0-6)
511 602	Selected Topics in Mathematics II	3(3-0-6)
511 603	Selected Topics in Mathematics III	3(3-0-6)
511 604	Selected Topics in Mathematics IV	3(3-0-6)
511 605	Selected Topics in Mathematics V	3(3-0-6)
511 611	Representation Theory of Finite Groups	3(3-0-6)
511 612	Advanced Linear Algebra	3(3-0-6)
511 613	Duality Theory	3(3-0-6)
511 641	Applied Functional Analysis	3(3-0-6)
511 682	Mathematical Theory of Inverse Problems	3(3-0-6)
511 683	Numerical Methods for Image Registration	3(3-0-6)
511 684	Quantum Computing	3(3-0-6)
511 685	Advanced Numerical Methods	3(3-0-6)
511 711	Selected Topics in Algebra I	3(3-0-6)
511 712	Selected Topics in Algebra II	3(3-0-6)
511 713	Selected Topics in Universal Algebra	3(3-0-6)
511 731	Selected Topics in Graph Theory	3(3-0-6)
511 732	Selected Topics in Coding Theory	3(3-0-6)

511 741	Selected Topics in Analysis I	3(3-0-6)
511 742	Selected Topics in Analysis II	3(3-0-6)
511 761	Selected Topics in Computational Science I	3(3-0-6)
511 762	Selected Topics in Computational Science II	3(3-0-6)
511 781	Selected Topics in Applied Mathematics I	3(3-0-6)
511 782	Selected Topics in Applied Mathematics II	3(3-0-6)
511 783	Selected Topics in Applied Analysis I	3(3-0-6)
511 784	Selected Topics in Applied Analysis II	3(3-0-6)
511 793	Seminar in Advanced Mathematics III	2(0-4-2)
511 795	Research Study in Mathematics II	1(0-2-1)

Thesis

Type 2.1

511 893	Thesis (equivalent to)	36 credits

Type 2.2

511 891	Thesis (equivalent to)	48 credits

Course Descriptions

511 513 Abstract Algebra I 3(3-0-6)

Condition: only with the approval of the department.

Permutation and symmetric groups. Sylow theorems and applications. Finitely generated abelian groups. Free groups. Basic properties of rings and fields. Unique factorization domains. Polynomial rings. Introduction to finite fields.

511 514 Abstract Algebra II 3(3-0-6)

Prerequisite: 511 513 Abstract Algebra I
or only with the approval of the department.

Chinese remainder theorem. Field extensions, degree of an extension, algebraic and transcendental extensions, normal and separable extensions. Galois theory. Finite fields and applications. Introduction to algebraic geometry. Modules.

511 515 Linear Algebra with Applications 3(3-0-6)

Vector spaces. Linear transformations. Linear functionals. Diagonalization. Jordan canonical forms. Inner product spaces. Orthonormal basis. Spectral decomposition. Applications.

511 517 Lattice Theory 3(3-0-6)

Lattices as ordered sets. Complete lattices. The Dedekind-MacNeikke Completion. Fixpoint theorems. Algebraic structures of lattices. Modularity and semimodularity. Congruences on lattices. Representation theorem. Ideals and filters.

511 518 Universal Algebra 3(3-0-6)

Prerequisite: 511 513 Abstract Algebra I
or only with the approval of the department.

The elements of universal algebra. Lattices and Boolean algebras as universal algebras and their applications. Birkhoff's subdirect representation theorem. Equational classes and congruence distributivity. Free algebra. Selected topics of interest.

511 519 Applicable Algebra 3(3-0-6)
Condition: only with the approval of the department.
Algebraic ideas applied to computer algebra, network communication, and other areas. Algebraic coding theory. Cryptography. Selected topics of interest.

511 521 Analytic Number Theory 3(3-0-6)
Arithmetic functions. Dirichlet series. Riemann zeta function. L-functions. Dirichlet's theorem. The prime number theorem.

511 522 Algebraic Number Theory 3(3-0-6)
Condition: only with the approval of the department.
Algebraic numbers and algebraic integers. Algebraic number fields and rings of algebraic integers. Integral basis and discriminant. Ideals and decomposition of ideals. Norm and classes of ideals. Geometric representation of algebraic numbers. Dirichlet's unit theorem.

511 532 Graph Theory 3(3-0-6)
Graphs and subgraphs. Trees. Connectivity. Matchings and factorization of graph. Eulerian graphs. Hamiltonian graphs. Planar graphs. Colorings and the four color theorem.

511 533 Combinatorics 3(3-0-6)
The pigeonhole principle and Ramsey's theorems. Generating functions. Recurrence relations. The inclusion-exclusion principle. Polya's theorem. Block designs.

511 541 Mathematical Analysis 3(3-0-6)
Real number system. Metric and topological spaces. Limits of sequences. Series. Continuous functions. Differentiation. Riemann integral. The generalized Riemann integral.

511 544 Real Analysis 3(3-0-6)
Condition: only with the approval of the department.
Algebras of sets. Outer measure. Lebesgue measure. Measurable functions. Riemann and Lebesgue integrals. Differentiation and integration. General measure and integration. The L^p spaces.

511 546 Complex Analysis 3(3-0-6)
Condition: only with the approval of the department.
Complex number system. Analytic functions. Complex integration. Cauchy's theorem. Singularities. Maximum principles. Sequences and series of analytic functions. Riemann's mapping theorem.

511 547 Advanced Complex Analysis 3(3-0-6)
Prerequisite: 511 546 Complex Analysis
or only with the approval of the department.
Weierstrass factorization theorem. Runge's theorem. Harmonic functions. Picard theorem. Analytic continuation and Riemann surfaces.

511 548 Complex Dynamics 3(3-0-6)

Prerequisite: 511 546 Complex Analysis
or only with the approval of the department.

Iteration of functions. Topology on the extended complex plane. Rational functions. Topology on the rational functions. Conjugacy. Fixed points. Critical points. Fatou sets. Julia sets. Dynamics of Newton maps.

511 549 Functional Analysis 3(3-0-6)

Condition: only with the approval of the department.

Complete metric spaces. Normed spaces. Hilbert spaces. Banach spaces. Linear functionals and linear operators. Orthogonal systems. Fundamental theorems for normed and Banach spaces.

511 552 Theory of Ordinary Differential Equations 3(3-0-6)

Physical problems and ordinary differential equations. Theory of first-order ordinary differential equations. Existence and uniqueness theorems. Linear systems of first-order ordinary differential equations. Stability of the linear systems. Stability of the nonlinear systems. Lyapunov method.

511 555 Multigrid Techniques for Differential Equations 3(3-0-6)

Finite difference methods for ordinary and partial differential equations. Basic iterative methods for finite difference equations. Basic idea and theory of multigrid methods. Nonlinear multigrid method. Multigrid method for singular problems. Selected applications.

511 556 Variational Techniques and Partial Differential Equations in Image Sciences 3(3-0-6)

Basic concepts of image sciences. Calculus of variations. Sobolev space and the space of functions of bounded variation. Image denoising. Image inpanting. Image segmentation. Optical flow computation. Image registration.

511 557 Linear Differential Operators in Mathematical Physics 3(3-0-6)

Generalized functions. Sobolev spaces. Weak solutions. Applications of mathematical methods to problems of electro-magnetism, elasticity, heat conduction and propagation of waves.

511 558 Partial Differential Equations 3(3-0-6)

Condition: only with the approval of the department.

First and second-order partial differential equations. Elliptic, hyperbolic and parabolic equations. Existence and uniqueness solutions. Maximum principles. Methods of solving partial differential equations. Green's functions.

511 559 Theory of Partial Differential Equations 3(3-0-6)

Condition: only with the approval of the department.

Fundamentals of partial differential equations. Representation formulas for solutions. Sobolev spaces. Second-order elliptic equations.

511 572 Probability Theory 3(3-0-6)
Condition: only with the approval of the department.
Axiomatic theory of probability. Probability measures. Independent random variables. Probability distributions on R^n. Characteristic functions. Gaussian random variables. Convergence of random variables. Weak and strong laws of large numbers. Central Limit Theorem. Martingales.

511 573 Stochastic Processes 3(3-0-6)
Condition: only with the approval of the department.
Elements of stochastic processes. Poisson processes. Renewal theory. Markov chains. Martingales. Random walks. Brownian motion.

511 582 Mathematical Modeling 3(3-0-6)
Some essential features of modeling. Types of mathematical models. Model building and modeling process. Analytical stages of model building. Case studies.

511 583 Numerical Analysis I 3(3-0-6)
Accuracy of approximations. Analysis of nonlinear algebraic equations and numerical solutions. Analysis of numerical differentiations and integrations. Analysis of numerical solutions of differential equations. Curve fitting. Interpolations. Data filtering.

511 584 Numerical Analysis II 3(3-0-6)
Prerequisite: 511 583 Numerical Analysis I
or only with the approval of the department.
Difference equations and solutions. Finite difference method. Numerical solutions of integral equations. Finite element method. Finite volume method. The applications of numerical techniques for solving differential equation problems.

511 589 Information Theory 3(3-0-6)
Condition: only with the approval of the department.
Introduction to information theory. Entropy. Mutual information. Shannon's source coding theory. Data compression. Huffman coding. Kraft inequality. Kolmogorov complexity. Channel capacity. Differential entropy. Gaussian channels. Maximum entropy and applications.

511 594 Seminar I 2(0-4-2)
Condition: only with the approval of the department.
Graded as S or U.
Seminar on topics of interest in mathematics.

511 595 Seminar II 2(0-4-2)
Condition: only with the approval of the department
Graded as S or U.
Seminar on topics of interest in mathematics.

511 601 Selected Topics in Mathematics I 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in mathematics relevant and complementary to current research and topics of current interest.

511 602 Selected Topics in Mathematics II 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in mathematics relevant and complementary to current research and topics of current interest.

511 603 Selected Topics in Mathematics III 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in mathematics relevant and complementary to current research and topics of current interest.

511 604 Selected Topics in Mathematics IV 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in mathematics relevant and complementary to current research and topics of current interest.

511 605 Selected Topics in Mathematics V 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in mathematics relevant and complementary to current research and topics of current interest.

511 611 Representation Theory of Finite Groups 3(3-0-6)
Prerequisite: 511 513 Abstract Algebra I
or only with the approval of the department.
Fundamental concepts of group representations. G-module and the group algebra. Reducibility. Maschke's theorem. Schur's lemma. Commutant and endomorphism algebras. Group characters. Schur orthogonality relations. Fourier analysis on finite groups. Restricted and induced representations. Representations of affine groups, Heisenberg groups, and symmetric groups.

511 612 Advanced Linear Algebra 3(3-0-6)
Condition: only with the approval of the department.
Inner product space. Cayley-Hamilton theorem and minimum polynomials. Orthogonal and unitary similarity. Normal matrices. Linear functionals. Bilinear, quadratic and Hermitian forms. Canonical forms and elementary divisors. Jordan and rational canonical forms.

511 613 Duality Theory 3(3-0-6)
Condition: only with the approval of the department.
Categories. Structured topological spaces. Predualities. Natural Dualities. Full duality and the dual category. Strong dualities. Dualisable Algebras. Applications.

511 641 Applied Functional Analysis 3(3-0-6)
Prerequisite: 511 549 Functional Analysis
or only with the approval of the department.
Banach spaces. Fixed-point theorems. Continuity and convexity. Compactness of operators. The Leray-Schauder principles. Banach algebras and applications.

511 642 Topology 3(3-0-6)

Topological spaces. Compact and locally compact spaces. Connected and locally connected spaces. Countability axioms. Separability axioms. Product spaces. Topology of the plane. Euclidean spaces.

511 643 Differentiable Manifolds 3(3-0-6)

Manifolds. Smooth maps. Tangent vectors. Vector fields. Vector bundles.

511 681 Principles of Applied Analysis 3(3-0-6)

Finite dimensional vector spaces. Eigenvalue problems. Integral equations. Regular perturbation theory. Singular perturbation theory.

511 682 Mathematical Theory of Inverse Problems 3(3-0-6)

Fundamental properties of an ill-posed inverse problem. Basic theorems for the construction and analysis of regularization methods. General theory of regularization. Classical regularization methods. Truncated singular value decomposition. Tikhonov and iterative regularization methods. The projection methods.

511 683 Numerical Methods for Image Registration 3(3-0-6)

Image registration problems. Digital images. Mathematical setting. Similarity measures. Mathematical models for parametric and non-parametric image registration. Calculus of variation. Regularization techniques for image registration. Numerical solution methods for elastic-, diffusion-, and curvature-based image registrations.

511 684 Quantum Computing 3(3-0-6)

Condition: only with the approval of the department.

Introduction to quantum computation and quantum mechanics. Model of quantum computation. Quantum algorithms. Shor's factoring algorithm. Grover's search algorithm. Hidden subgroup problems. Quantum error-correcting codes.

511 685 Advanced Numerical Methods 3(3-0-6)

Condition: only with the approval of the department.

Stationary and nonstationary methods. Analysis of finite difference, finite element, and finite volume methods. Multigrid methods.

511 711 Selected Topics in Algebra I 3(3-0-6)

Condition: only with the approval of the department.

Selected topics in advanced algebra relevant and complementary to current research and topics of current interest.

511 712 Selected Topics in Algebra 2 3(3-0-6)

Condition: only with the approval of the department.

Selected topics in advanced algebra relevant and complementary to current research and topics of current interest.

511 713 Selected Topics in Universal Algebra 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in universal algebra relevant and complementary to current research and topics of current interest.

511 731 Selected Topics in Graph Theory 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in advanced graph theory relevant and complementary to current research and topics of current interest.

511 732 Selected Topics in Coding Theory 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in coding theory relevant and complementary to current research and topics of current interest.

511 741 Selected Topics in Analysis I 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in advanced analysis relevant and complementary to current research and topics of current interest.

511 742 Selected Topics in Analysis II 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in advanced analysis relevant and complementary to current research and topics of current interest.

511 761 Selected Topics in Computational Science I 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in computational science relevant and complementary to current research and topics of current interest.

511 762 Selected Topics in Computational Science II 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in computational science relevant and complementary to current research as well as those of current interest.

511 781 Selected Topics in Applied Mathematics I 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in applied mathematics relevant and complementary to current research and topics of current interest.

511 782 Selected Topics in Applied Mathematics II 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in applied mathematics relevant and complementary to current research and topics of current interest.

511 783 Selected Topics in Applied Analysis I 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in applied analysis relevant and complementary to current research as well as those of current interest.

511 784 Selected Topics in Applied Analysis II 3(3-0-6)
Condition: only with the approval of the department.
Selected topics in applied analysis relevant and complementary to current research and topics of current interest.

511 791 Seminar in Advanced Mathematics I 2(0-4-2)
Condition: only with the approval of the department.
Graded as S or U.
Seminar on current research in advanced mathematics.

511 792 Seminar in Advanced Mathematics II 2(0-4-2)
Condition: only with the approval of the department.
Graded as S or U.
Seminar on current research in advanced mathematics.

511 793 Seminar in Advanced Mathematics III 2(0-4-2)
Condition: only with the approval of the department.
Graded as S or U.
Seminar on current research in advanced mathematics.

511 794 Research Study in Mathematics I 1(0-2-1)
Condition: only with the approval of the department.
Graded as S or U.
Study, gather, compile, and present results from articles related to thesis. Write a report.

511 795 Research Study in Mathematics II 1(0-2-1)
Condition: only with the approval of the department.
Graded as S or U.
Progess report on thesis research. Write a research article.

511 891 Thesis (equivalent to) 48 credits
Research topics in mathematics under the supervision of thesis advisor(s).

511 892 Thesis (equivalent to) 72 credits
Research topics in mathematics under the supervision of thesis advisor(s).

511 893 Thesis (equivalent to) 36 credits
Research topics in mathematics under the supervision of thesis advisor(s).

Graduation criteria

Graduation criteria shall be in accordance with Silpakorn University's Regulations on Graduate Study B.E. 2550 (2007), Section 7. The addition criterions are the following.

The results of student thesis work for students in Type 1 must be accepted for at least 2 publications in international journals, or at least 1 publication in an international journal and an oral presentation in an international conference, and that for students in Type 2, at least 1 publication in a peer-review international journal is required.